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MEMORANDUM
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DECEMBER 1962

COMPARISON OF MONTE CARLO CALCULATIONS WITH EXPERIMENTAL RESULTS FOR THE PROPAGATION OF GAMMA RAYS NEAR AN AIR-GROUND INTERFACE

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PREPARED FOR:

UNITED STATES AIR FORCE PROJECT RAND

The RAND Corporation
SANTA MONICA • CALIFORNIA

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PREFACE

RAND was one of the first to make use of the Monte Carlo method for the solution of complicated problems involving nuclear radiation. This method has been useful chiefly when solution by other means was prohibitively complicated.

This report gives the solution to a particular problem involving the propagation of neutrons or gamma rays, and is one of a continuing series. It should be useful as a guide for those offices and other research organizations that now have copies of the RAND Monte Carlo gamma ray propagation code.

SUMMARY

The RAND gamma ray Monte Carlo code is used to predict dosages from point isotropic monoenergetic sources of 1.28 Mev and 0.661 Mev near an air-ground interface. These results are compared with experimental results for identical geometry obtained by the Nuclear Defense Laboratory. In general the agreement between the Monte Carlo estimates and the experimental results is quite good.

CONTENTS

PREFACE iii

SUMMARY v

Section

I. INTRODUCTION 1

II. GAMMA RAY PROPAGATION NEAR AN AIR-GROUND INTERFACE .. 2

III. A COMPARISON OF EXPERIMENTAL DATA AND MONTE CARLO CALCULATIONS 3

IV. POSSIBLE ERRORS AND INACCURACIES IN THE MONTE CARLO SOLUTION 5

General Statistical Inaccuracy 5
Lower Energy Limit 5
Monte Carlo Bias Error 5
Error Due to Inaccurate Ground Composition 6

V. FURTHER WORK 7

VI. CONCLUSIONS 8

FIGURES 9

Appendix

ADDENDUM ON MACHINE RUNNING TIME 17

REFERENCES 19

I. INTRODUCTION

Sometime ago RAND's Monte Carlo neutron transport code was changed to a gamma ray transport code by introducing pertinent cross sections. The main assumptions of this code are a point source, usually but not necessarily isotropic, an exponential atmosphere, and a ground of the same composition as air but with the density of earth.

Many problems have been run by means of this gamma ray code, but because of various difficulties peculiar to the nature of gamma ray propagation the results have not yet been published. These difficulties have now been reasonably resolved, and the present study gives the solution to a typical problem using this code.

II. GAMMA RAY PROPAGATION NEAR AN AIR-GROUND INTERFACE

A problem which has been of considerable interest for a number of years is the modification in the propagation of gamma rays introduced by the presence of the ground as compared with propagation in a infinite homogeneous air medium. Using a uniform atmosphere and an infinitely dense atmospheric "ground," Berger[1] used the Monte Carlo method in attacking some aspects of this problem. His results showed that the presence of the dense interface increased the dosage near the source but decreased it away from the source.

There have been several experimental measurements of the perturbation in gamma ray propagation caused by a dense interface. In this paper a comparison will be made only with a detailed set of experimental data recently obtained by the Nuclear Defense Laboratory.[2] In this experiment, cobalt^{60} (E_o= 1.28 Mev) and cesium^{137} (E_o= 0.661 Mev) sources were placed at a height of two inches above a large level field, to simulate point isotropic sources. Gamma doses at heights of 1, 3, and 6 feet were measured from horizontal distances of 2 to 800 feet.

III. A COMPARISON OF EXPERIMENTAL DATA AND MONTE CARLO CALCULATIONS

Figures 1-6 show the results obtained by the RAND Monte Carlo code in comparison with the experimental results obtained by NDL.[2] The notation used in these figures is the same as that used by Berger.[1] K is the ratio obtained by dividing the actual roentgen dosage at a given point by the dosage that would be obtained at that same point for an infinite homogeneous air medium of the same density as the air above the interface. The abscissa on these curves is the horizontal distance from source to detector measured in mean free paths of the source radiation energy.

In order to present the data in the form given in Figs. 1-6, which conforms to the form used in Berger's[1] paper, rather than that given in NDL-TR-2[2] it is necessary to use the result of some calculation for the dosage in an infinite homogeneous medium in order to obtain K. Only one quantity, the build-up factor, is necessary to make such a calculation. The build-up factors used in Figs. 1-6 were taken from NYO-3075[3] and were obtained by interpolation from Table 7.112, page 135, for a point isotropic source in water. The build-up factor for E_o= 1.28 Mev is very nearly identical to that in Berger's[1] paper, in NDL-TR-2[2] and in the interpolation from NYO-3075[3]. It is shown in the graph in Fig. 7. There is, however, a substantial discrepancy in the build-up factor for E_o= 0.661 Mev between the values interpolated from NYO-3075 and the NDL-TR-2 curve. Both of these results for E_o = 0.661 Mev are also shown in Fig. 7, but the data from NYO-3075 were in fact used in the preparation of Figs. 4, 5 and 6.*

It can be seen from Figs. 1-6 that the discrepancy between the Monte Carlo calculations and the experimental results is in general fairly small, the error being on the average less than 5 per cent and at most about 10 per cent.

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*The build-up factor for E_o= 0.661 Mev has also been calculated with the RAND Monte Carlo gamma ray propagation code for the case of an infinite homogeneous medium. The results are in very close agreement with the curve interpolated from NYO-3075.

Included in Fig. 1 is Berger's results for a 1.28 Mev source when both the source and the detector are located on the dense interface. His results are essentially the same as the present results at distances greater than 0.25 mean free paths, but differ considerably at shorter distances between source and detector. This is not surprising because at short source-detector distances the results are very sensitive to the geometry employed.

IV. POSSIBLE ERRORS AND INACCURACIES IN THE MONTE CARLO SOLUTION

GENERAL STATISTICAL INACCURACY

Statistical inaccuracy due to finite sampling in Monte Carlo problems is a well-discussed subject. It can be lessened by various modifications in the Monte Carlo method, but even then there always remains a residual statistical uncertainty which can only be eliminated at the expense of additional machine running time. The problem presented in this report used a sample comprising 12,750 histories, and it is estimated that the average statistical fluctuation results in errors of about 5 to 15 per cent for any particular dosage at a point in the sample space. A smoothing scheme,* has been used, however, to average the results spatially, which reduces the error at particular points by at least a factor of two and probably more, leaving the residual statistical uncertainty at less than 5 per cent.

LOWER ENERGY LIMIT

The photons in the Monte Carlo code are followed down to some lower energy limit, in this case 20 Kev for E_o = 0.661 Mev and 50 Kev for E_o = 1.28 Mev. No correction has been made for energy dissipation below this limit. In the case of the 1.28 Mev source, this omission results in an error of about 4 per cent; for the 0.661 Mev source, an error of 3 per cent. No corrections have been made to compensate for this error. Nor have any additions to the dosage been made for such secondary phenomena as fluorescence radiation, which might result in another 1 per cent error.

MONTE CARLO BIAS ERROR

Because of the nature of the sampling scheme used in the Monte Carlo code, bias errors can result which are possibly as high as 10 per cent but are probably closer to 5 per cent. A complete discussion

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*The method used here was to take successive moving averages, three points at a time, of the slowly varying function, K. A machine code was devised for this purpose.

of this type of error in the RAND Monte Carlo code and how it arises will be found in a memorandum by the author.[4] This type of error always makes the result too low and could conceivably be corrected for intuitively, though no corrections of this type have been made in the results presented in this report.

As a further consequence of bias errors, the Monte Carlo results can be unusually high, at some very few points, sometimes by as much as a factor of 2 or 3. Theoretically, these excessively high points compensate for the bias loss over most of the rest of the sample space. They can be removed, however, by a truncation procedure in the sampling process, and this in fact has been done in the present results.

ERROR DUE TO INACCURATE GROUND COMPOSITION

In assuming the chemical composition of the ground to be the same as that of air, a small error is made. Though there is no way of exactly assessing the magnitude of this error, it seems to be less than 5 per cent using infinite homogeneous medium build-up factors for common soil elements as a basis of comparison.

V. FURTHER WORK

An important extension of the calculations of this report deals with the general subject of deep penetrations: the extension of the results from two or three mean free paths as given here to 10 or 20 mean free paths. Attempts have already been made to solve problems of this type with the RAND Monte Carlo code with varying degrees of success. The basic difficulty is that the statistical inaccuracy becomes progressively larger quite rapidly as the penetration is carried beyond 5 or 6 mean free paths. Several variations in the Monte Carlo method are employed to overcome this difficulty, and seemingly meaningful results have been obtained out to about 10 mean free paths. There is an important and as yet unanswered question as to whether the boundary correction factor K keeps declining in a more or less logarithmic manner as predicted by Berger[(1)] or at a considerably slower rate as preliminary indications with our Monte Carlo codes seem to indicate. This problem is currently being investigated.

VI. CONCLUSIONS

A comparison of the experimentally obtained data and the results calculated with the RAND gamma ray transport code show that this code may be used to predict gamma ray dosages with very good accuracy in the vicinity of an air-ground interface.

In spite of a large number of possible errors in both theoretical calculations and experimental measurements, the agreement is generally within 5 per cent, though this close agreement may possibly be somewhat fortuitous. It is believed that under the conditions presupposed by the type of problem solved here gamma ray dosages can almost certainly be predicted with an error of less than 10 per cent by means of the RAND Monte Carlo code. This degree of accuracy should certainly be sufficient for most practical applications.

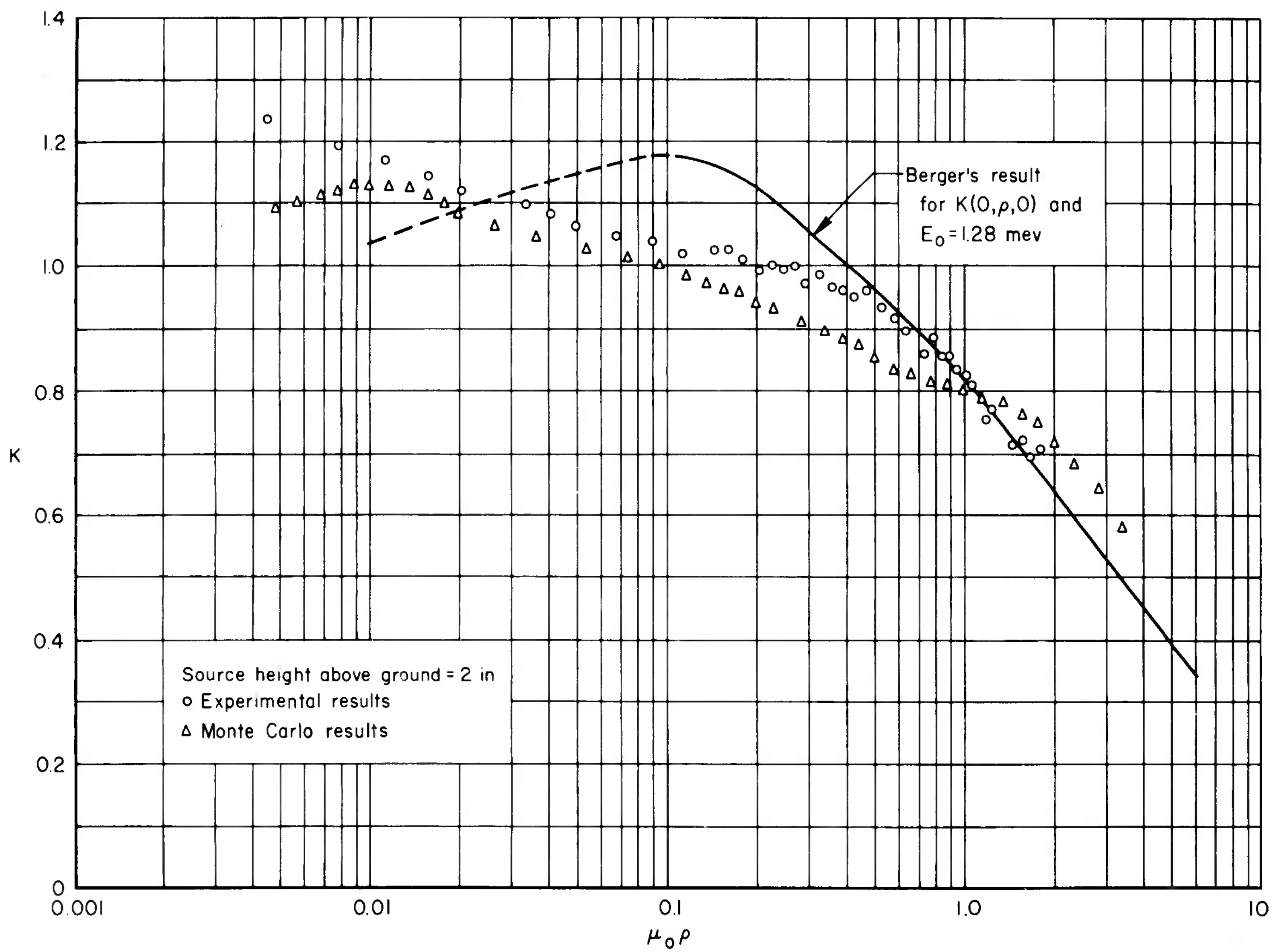

Fig. 1—Boundary correction factor for E_0=1.28 mev and observation level=1 ft

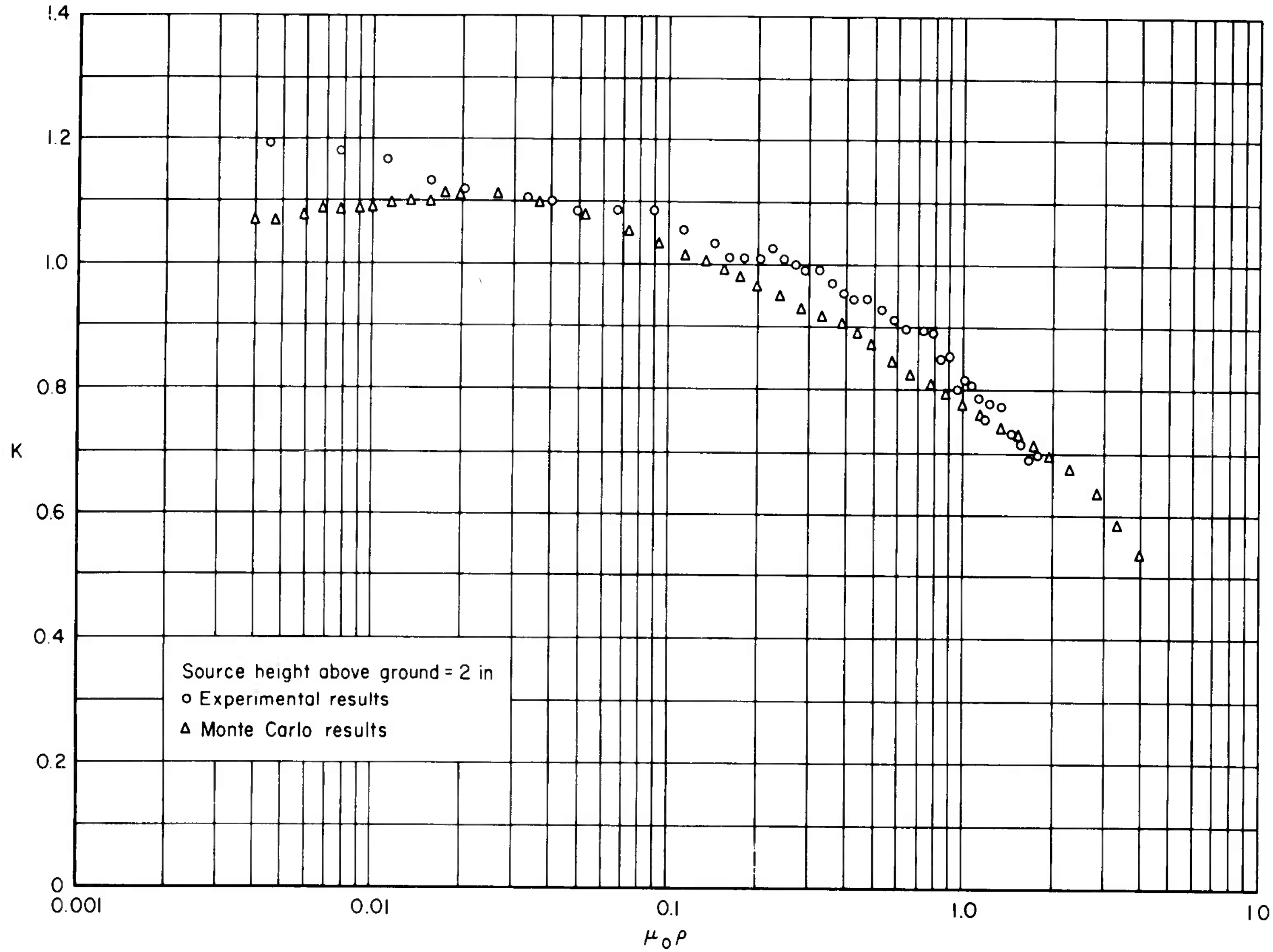

Fig. 2—Boundary correction factor for E_0=1.28 mev and observation level=3 ft

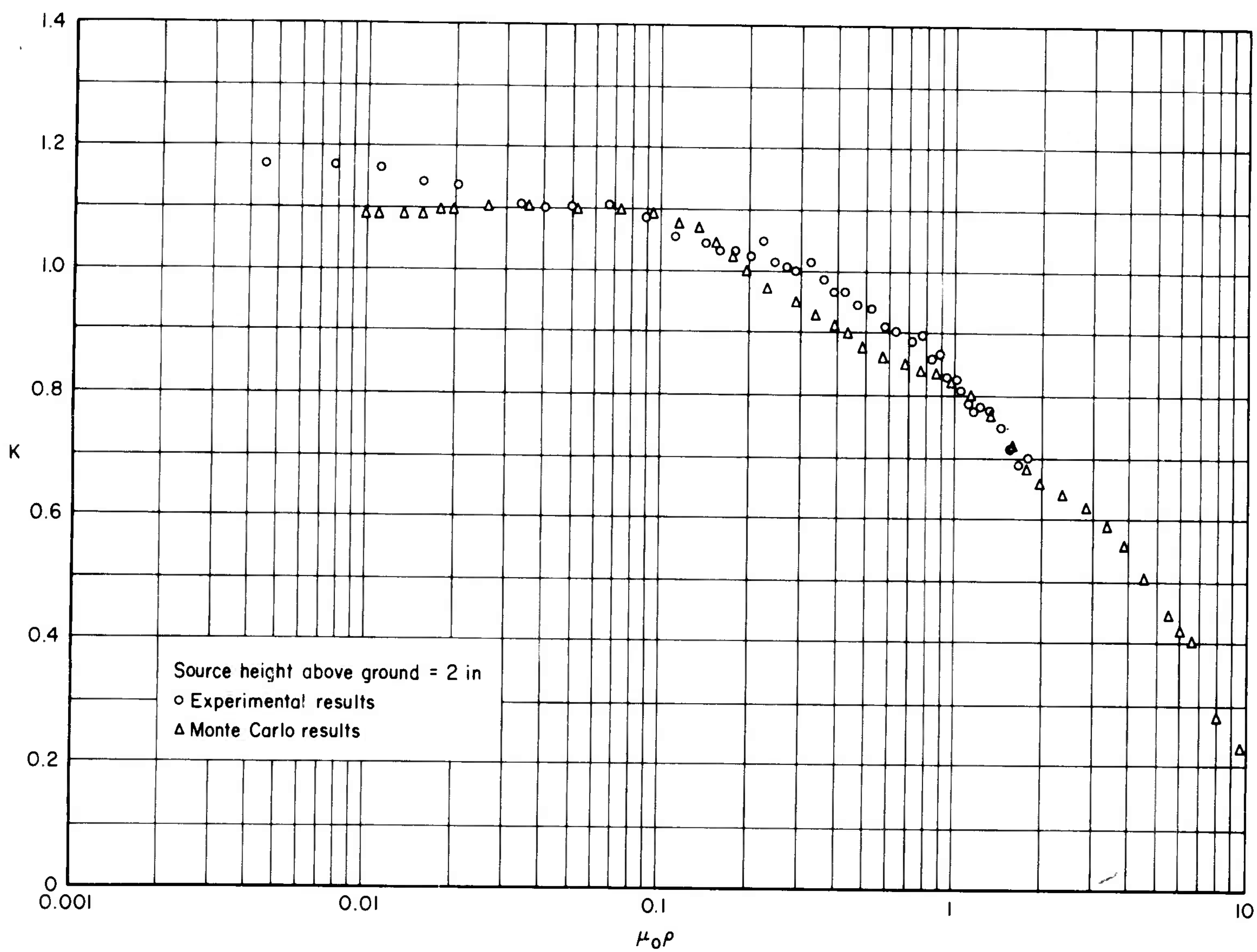

Fig. 3—Boundary correction factor for E_0= 1.28 mev and observation level = 6 ft

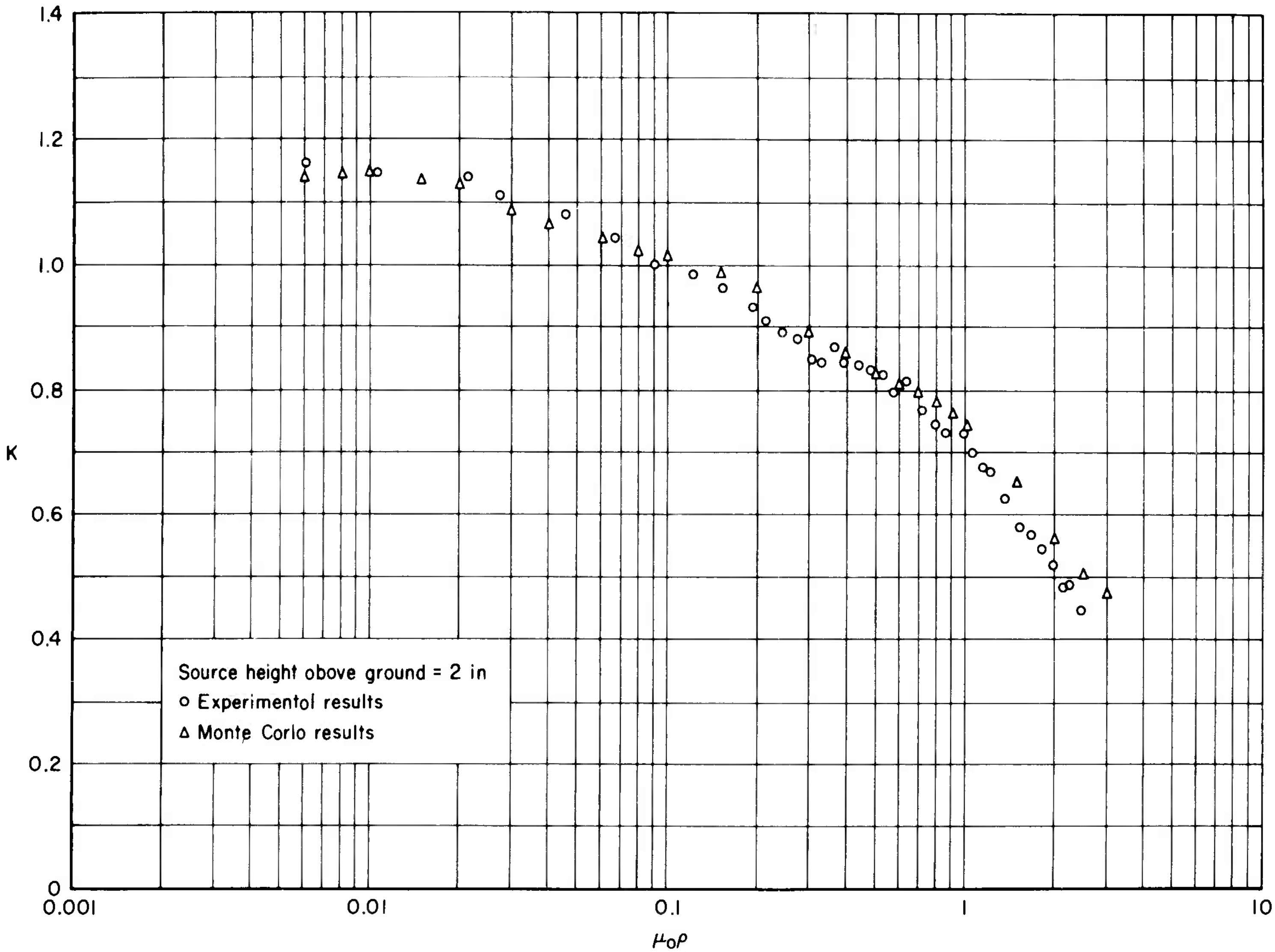

Fig. 4 — Boundary correction factor for $E_0 = 0.661$ mev and observation level = 1 ft

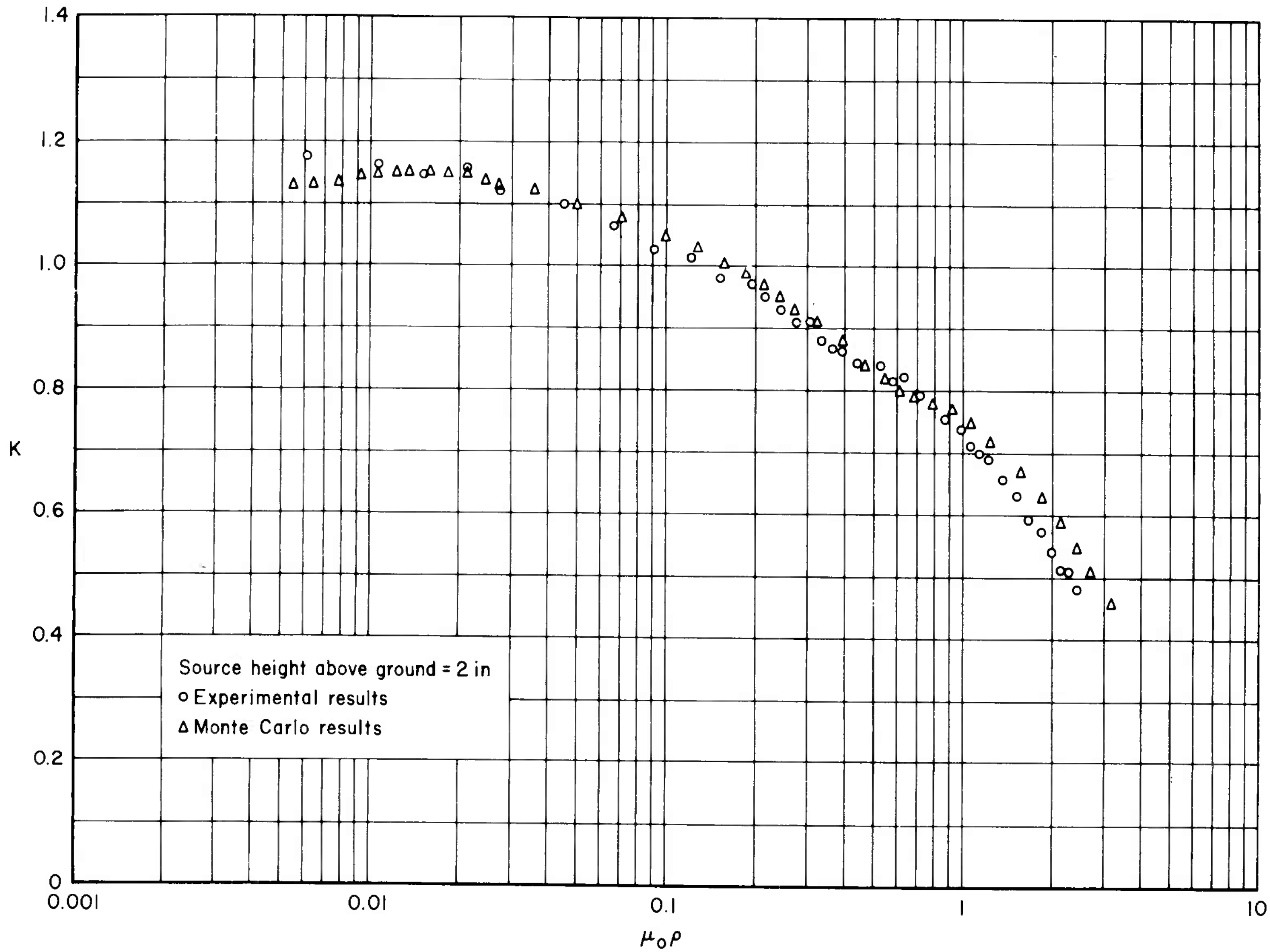

Fig. 5—Boundary correction factor for E_o = 0.661 mev and observation level = 3 ft

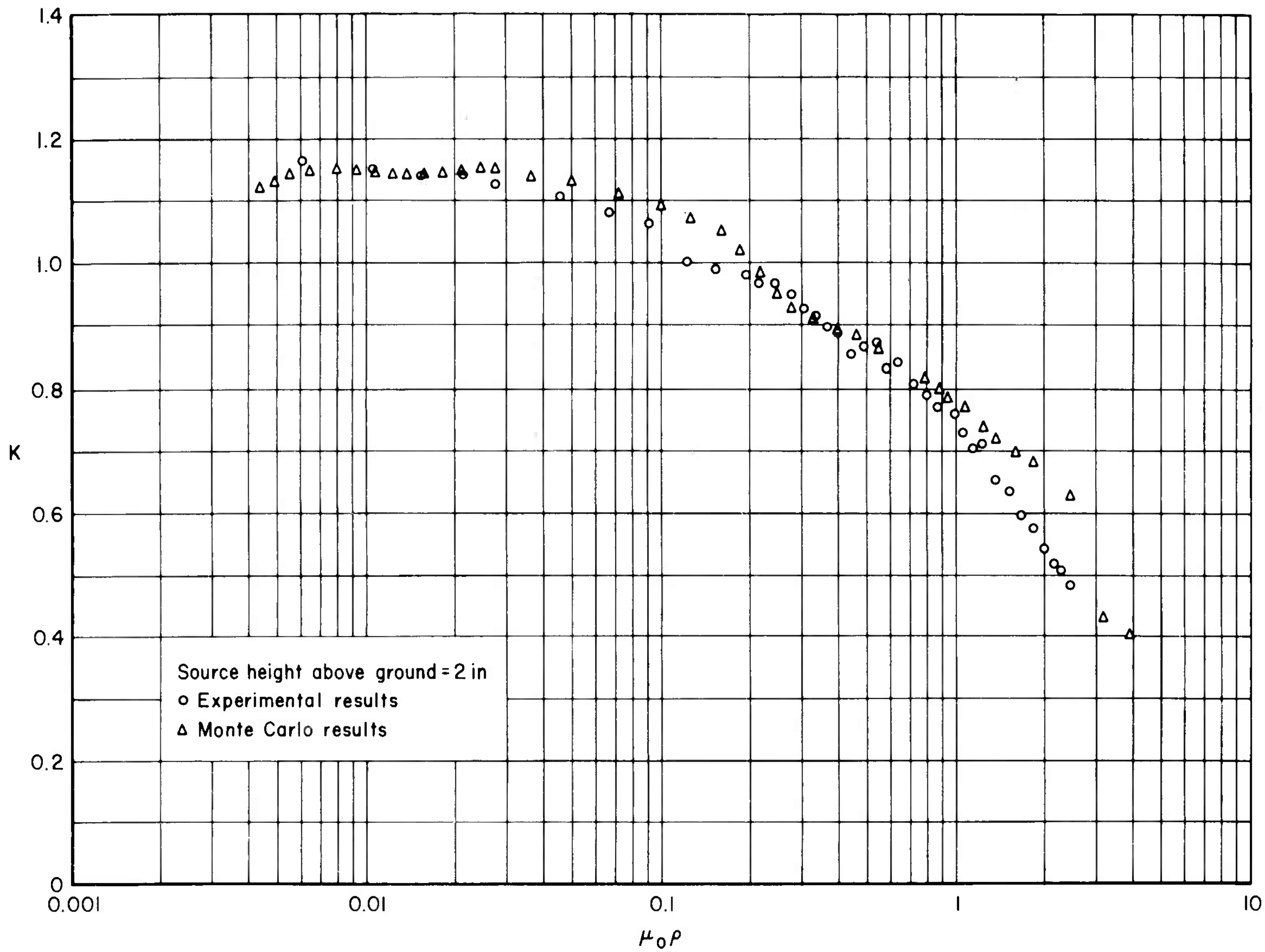

Fig. 6—Boundary correction factor for E_0=0.661 mev and observation level = 6 ft

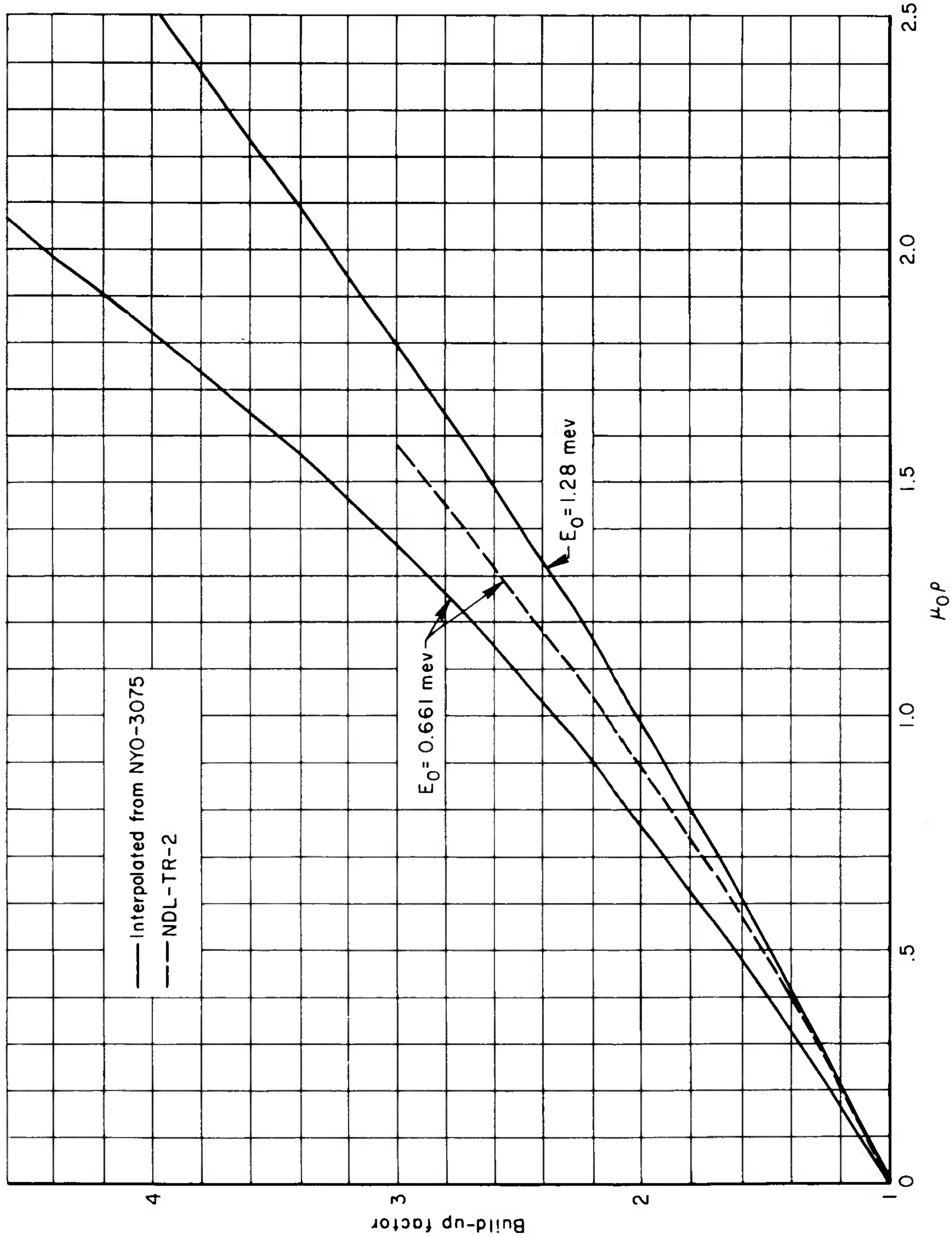

Fig. 7 — Build-up factors for infinite homogeneous medium

Appendix

ADDENDUM ON MACHINE RUNNING TIME

The machine times involved in the two problems run in conjunction with this report are:

E_o = 0.661 Mev

7090 time for main Monte Carlo problem	6.7 hours
7090 time for data smoothing and for computing direct beam (unscattered flux)	2 minutes
Printing time for main Monte Carlo problem	2 minutes
Printing time for data smoothing and for computing direct beam (unscattered flux)	5 minutes

E_o = 1.28 Mev

7090 time for main Monte Carlo problem	3.5 hours
7090 time for data smoothing and for computing direct beam (unscattered flux)	2 minutes
Printing time for main Monte Carlo problem	2 minutes
Printing time for data smoothing and for computing direct beam (unscattered flux)	5 minutes

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